FAST FLUIDIZED BED REACTOR

This invention relates to the geometry of peripheral walls in the lower regions of combustion chambers in fast fluidized bed reactors. The walls are generally downwardly and inwardly inclined and typically have a relatively dense film of particles flowing downwardly close to their surfaces. This heavy particle flow causes problems when it reaches the grid plate at the bottom of the combustion chamber because the fluidizing gas from the nozzles or holes in the grid is not entirely capable of satisfactorily fluidizing the particles. A pulsation of particles and gas is created close to the grid plate which leads to grid leakage mainly through the first three peripheral rows of grid nozzles.

Fast fluidized bed reactors are typically used in a variety of different processes such as combustion, gasification and heat transfer processes. Fast fluidized bed reactors are also used in heat generation, as well as in chemical and metallurgical processes. Depending upon the particular processes, particulate fuel such as coal, lignite, wood waste and peat as well as other particulate matter such as sand, limestone, ash, catalysts and metaloxides are fluidized in the reactor. In fast fluidized bed reactors very fine 10-300 µm particulate material can also be used.

The fast fluidized bed reactor utilized in combustion processes comprises an upright combustion chamber, having substantially vertical peripheral walls. The walls in the lower region of the combustion chamber are usually inwardly inclined (slanting) and made as refractory walls to withstand the heat in the bottom region of the combustion chamber. The upper walls in the reactor are made as tube walls. The combustion chamber has one or more inlets for the particulate material which is to be combusted. Inlets for other particulate material such as limestone for sulphur capture are also provided in the reactor. Inlets for secondary air can be disposed at different levels in the peripheral walls. Primary air is normally supplied to the combustion chamber through a windbox or air chamber beneath the combustion chamber. The air is supplied through nozzles or holes in a grid plate which is disposed between the combustion chamber and the windbox. In a fast fluidized bed, air is supplied through the nozzles at a velocity high enough to fluidize the particles in the combustion chamber to a stage where a substantial portion of the particles are transported out of the combustion chamber with the exhaust gases. The velocity of the gas flow in the bed is about 2-10 m/s. A bed can be maintained in the combustion chamber only by recirculation of particles entrained with the gases and separated from the off gas by a high efficiency separator. The solids concentration in the combustion chamber decreases continuously up the chamber and does not show a definite border between a dense bed and a freeboard region.

Notwithstanding the high gas velocity the solids velocity in the combustion chamber is relatively low. The fast bed condition is marked by relatively high solid concentrations and aggregations of particles in clusters and strands. The fine particles flowing upward in the combustion chamber form clusters of particles which are heavy and fall downwards against the gas stream. The clusters break apart and reform in rapid succession. The particle behavior in the reactor leads to a uniform temperature throughout the reactor. Due to more efficient contact between gas and solids, high heat transfer rates are achieved as well as high reaction rates for other reactions in the combustor. Nearly complete carbon combustion is achieved as well as higher efficiency in limestone utilization in sulphur capture.

At specific locations in the combustion chamber, there are both downwards and upwards mass flow. The absolute mass flow varies in radial and axial directions in the combustion chamber. The absolute upwards mass flow has its maximum on the combustion chamber center-line whereas the downwards mass flow is extreme near the peripheral wall. The density of particle suspension and, consequently, the mass flows increase towards the lower region of the combustion chamber. This leads to a heavy downward flowing film of particles near the peripheral wall at the bottom of the combustion chamber. The downwardly flowing dense film of particles can be 10-50 mm thick and have additional particle layers of decreasing density and decreasing downward velocity inwardly of the dense film. The dense film causes pulsations at the grid area, plugging of nozzles and backflow of particles into the windbox. The backflow is localized to the border area between the peripheral wall and grid plate, this being observed by sparks emitted from the fine carbonaceous particles entering the windbox.

As the fluidized bed reactors are scaled up, the dense particle film flowing down the inclined walls grows and the problems related to this grow as well. It is essential for the combustion process and other reactions taking part in the combustor that particle and gas jets introduced into the lower regions reach as deep into the reactor chamber as possible. The dense bed in the lower region prevents particles and gases from reaching very far into the bed. In order to overcome this problem, the cross-sectional area of the combustion chamber in the lower dense regions is dimensioned to

allow particle or gas jets from th side walls to reach almost into the middle of the combustion chamber. As the cross-sectional area has to increase in an upward direction as the gas flow increases due to combustion, the sid walls must be upwardly and outwardly inclined. If the grid area is about 50% of the upper cross-sectional area, the projection of the side walls in the lower region is also 50% of the upper cross-sectional area. The projection of the side walls corresponds to the peripheral area of the upper cross-sectional area. Consequently, the side walls will receive substantially all particles flowing downwardly in the peripheral area of the combustion chamber.

The downwardly flowing particle film interferes with the fluidization and mixing of particles in the combustion chamber. Optimal process conditions demand a steady and equal supply of fluidizing and combustion air. Pulsations in the gas flow have detrimental effects on combustion efficiency as well as on other reactions taking place in the combustor.

Backflow of particles through the nozzles is especially a problem in the fast fluidized bed reactors due to the very fine material being fluidized. The fine particles can easily enough flow into the openings in the nozzles and interfere with the air supply through the nozzles as well as plug them totally. The backflow of material into the windbox leads to losses in fine carbonaceous material.

The particles can also cause the nozzles to wear out prematurely if the fine particles flow back and forth in the nozzle openings as a result of the pulsation in the reactor.

It has been suggested that backflow can be avoided by keeping the pressure difference over the grid plate sufficiently high or by increasing the flow of fluidizing air. But the backflow tendency in the nozzles near the peripheral wall is not easily avoided. In some reactors, the velocity in the openings in the nozzles has to be increased to relatively high levels, 60 m/s, to avoid backflow. This increases the power demand for air blowers. It is, of course, possible to increase the velocity in only the nozzles concerned, but that requires a rather complicated arrangement to supply nozzles with air from different air supply devices. It has also been suggested to use special nozzles designed to prevent backflow but does not solve the problem with the heavy particle film flowing downwards to the grid area.

While the problem of backflowing particles in fluidized beds is well known, and many solutions have been proposed, such solutions have not been entirely successful. It is believed that the cause of backflow and pulsation at the peripheral grid area has not been well understood. Therefore, it is believed that an optimum design of the lower region of the reactor, which provides an even distribution of fluidizing gas into the reactor, good mixing of bed material and optimal conditions for reactions taking place in the reactor, has not yet been provided.

It is therefore an object of the present invention to provide a design for the lower peripheral walls in the combustion chamber of a fluidized bed which minimizes or eliminates the above-mentioned problems with backflow, plugging of nozzles and pulsations.

It is another object of this invention to provide a design for the lower peripheral walls in the combustion chamber of a fluidized bed which interferes with the downwardly flowing relatively dense film of particles adjacent the wall.

It is a further object of the present invention to provide a design for the lower peripheral walls in the combustion chamber of a fluidized bed which promotes the fluidization of the particles flowing downwardly as a film along the combustion chamber wall.

According to a broad aspect of the present invention, a fast fluidized bed reactor is provided which comprises means for changing, at a height 200- 1100 mm above the grid plate, the direction of particles, flowing downwardly close to the inclined or slanting wall in the lower region of the combustion chamber. The means for changing the direction of the particles is disposed at a height < 1100 mm from the grid plate. Such changing means direct the particles for flow in a direction away from the wall.

The lower usually inclined walls in the combustion chamber are preferably made of refractory and preferably reach an elevation 2-4 m above the grid plate. The means which interfere with the particle flow along the inclined wall are disposed at a relatively low elevation along the refractory wall. If the means for breaking the particle film was disposed at a higher elevation, a new particle flow could build up at the wall.

In most reactors, two opposite walls, the front and back wall, are inclined at the bottom region. The cross-section of a reactor chamber is mostly rectangular, the front and back walls forming the long walls and the side walls being shorter. The front and back walls form an angle about 100-120° with the horizontal, the side walls perhaps only 90-100° with the horizontal. In some embodiments, only one wall can be inclined. In reactors having a circular cross-section, the walls in the lower region have a conical shape. The means interfering with the downward flowing particle film extend preferably continuously across the entire horizontal width of th slanting walls but could be made non-continuous if desired.

The inlets for particulate material such as fresh

fuel, limestone and recycled particles as well as secondary air are preferably added at an elevation above th particle flow interfering means.

A step in the inclined wall can effectively direct the particle film away from the wall. The step may be 200-1100 mm above the grid plate. The step changes the direction of the downwardly flowing particles so as to direct them inwardly in a direction to cross the fluidizing gas jets from the nozzles or holes in the grid plate. The gas will then fluidize at least a part of the particles which will be entrained by the gas flow. The step used to interfere with the particle film is preferably 300-1000 mm above the grid plate, most preferably at an elevation 300-700 mm above the grid plate. The height of the step can easily be adjusted to suit the mass flow in the reactor. The step has preferably a depth of 50-300 mm or more preferably 100-150 mm. Moreover, it is relatively easy to reconstruct the refractory in the lower combustion chamber to form a step according to the invention.

The particle film along the inclined wall can also be disturbed and disrupted by a ledge disposed at a height of about 200-1100 mm above the grid plate. The ledge can be designed to give the particle film flow a preferred direction. The ledge can easily be fastened in the refractory wall at a suitable elevation.

The particle film can also be disturbed by just changing the inclination of the wall to form an angle < 100° with the horizontal. In a preferred embodiment, the lowermost part of the refractory walls are made substantially vertical. The wall can even be arranged to form an angle < 90° at a height 200-1100 mm above the grid plate.

The present invention relates also to a method of operating a fast fluidizing bed reactor by changing the direction of particles flowing downwards along lower parts of peripheral walls in the combustion chamber, changing the direction of the particles at a height 200-1100 mm above the grid plate and causing the particles to flow in a direction to come into the range of gas jets supplied through the distributors in the grid plate.

It is the primary object of the present invention to provide for even distribution of fluidizing gas and to improve the combustion and heat transfer processes in the reactor while preventing backflow of solids into the gas nozzles and decreasing the dense particle flow along inclined walls in the lower region of the combustion chamber.

Other reactions taking place between solid particles and gas are also improved due to more even fluidization of particles. The elimination of the plugging tendency of nozzles is, of course, an improvement as well.

In a preferred embodiment of the present invention, there is provided a fast fluidized bed reactor comprising an upright combustion chamber having an upper region with generally vertical peripheral walls and a lower region with at least one generally downwardly and inwardly inclined peripheral wall for flow of a relatively dense layer of particles downwardly close to its surface, an inlet in the combustion chamber for particulate material to be reacted and an outlet disposed in the upper region of the combustion chamber for exhausting gas. A windbox is located beneath the combustion chamber for providing fluidizing gas to the combustion chamber, with a grid plate positioned between the windbox and the combustion chamber, the grid plate having openings for supplying gas from the windbox to the combustion chamber at a sufficient velocity to fluidize particulate material in the combustion chamber and to transport a portion of the particulate material out of the combustion chamber with the discharged exhaust gas. A particle separator is connected to the exhaust gas outlet for separating entrained particles from the exhaust gas, the separator having an outlet for clean gas and an outlet for particles connected to the lower part of the combustion chamber for recycling the separated particles into the combustion chamber. Means are provided inwardly of the inclined wall and above the grid plate for changing the direction of the particles flowing downwards close to the inclined wall for preventing clogging and backflow of particles through the openings into the windbox, the changing means being disposed adjacent the inclined wall for directing the particles to flow in a direction away from the wall.

In another aspect of the present invention, there is provided a method of operating a fast fluidizing bed reactor for combusting particulate material comprising the steps of supplying fluidizing gas to a combustion chamber through distributors in a grid plate at a sufficient velocity to fluidize the particulate material and transport a substantial portion of the particulate material out from the combustion chamber with exhaust gases, separating particles from the exhaust gas and recycling the separated particles to the combustion chamber, changing the direction of particles flowing downwardly along lower parts of peripheral walls in the combustion chamber at a height 200-1000 mm above the grid plate and causing the particles to flow in a direction so that the particles become influenced by the gas flowing through the distributors in the grid plate.

In the description, a fast fluidized bed reactor with combustion chamber is used to illustrate the present invention but the invention is applicable to other processes in fast fluidized bed reactors as well.

These and further objects and advantages of the present invention will become more apparent

upon reference to the following specification, appended claims and drawings.

Figure 1 is a schematic cross-sectional side view of a fast fluidized bed reactor according to one embodiment of this invention;

Figure 2 is an enlarged schematic vertical cross-sectional view of the lower part of a combustion chamber illustrated in Figure 1; and

Figures 3 through 6 are enlarged schematic vertical cross-sectional views of the lower part of a combustion chamber according to other embodiments of this invention.

Reference will now be made in detail to the present preferred embodiment of the invention, an example of which is illustrated in the accompanying drawings.

Figure 1 shows a fast fluidized bed reactor for combusting particulate carbonaceous material in the combustion chamber 2 of the reactor. The fuel is introduced at an inlet 3 at the lower part of the combustion chamber. Limestone is introduced at another inlet 4 for capturing sulphur released from the fuel. The particulate material in the combustion chamber is fluidized and combusted by air being introduced from a windbox or air chamber 5 beneath the combustion chamber. The air is distributed through holes or nozzles 6 in a grid plate 7. If gas other than air is used to fluidize the particulate material, air has to be introduced for combustion through special air nozzles.

The fluidizing air has a velocity sufficient to achieve a transport of a substantial portion of the particulate material out of the combustion chamber with the exhaust gases. The exhaust gases discharge through an outlet 8 into a cyclone separator 9. The particles entrained with the gas from the combustion chamber is separated from the gas in the highly efficient cyclone 9. The cleaned gases leave the cyclone through outlet 10. The separated particles are recirculated to the combustion chamber through cyclone particle outlet 11, recycling channel 12 and opening 13 in the combustion chamber wall.

The walls 14 in the upper region 15 of the combustion chamber are vertical tube walls. The walls 16 in the lower region 17 are preferably made as inclined refractory walls.

A step 18 is arranged in the inclined refractory wall, at the lowermost part 19 of the refractory wall. As can be seen in Figure 2, the direction of the downwardly flowing particle layer 20 is changed by the step 18 in the lowermost part of the refractory wall. The particles are directed towards the center of the combustion chamber and are fluidized by air introduced through the nozzle closest to the refractory wall.

Figure 3 shows another embodiment of the present invention. The refractory wall 16 is reconstructed at the lowermost part 19. The lowermost part 19 of the wall is substantially vertical from a point 21 disposed about 200-1100 mm from the grid plate. Figure 4 shows still another embodiment of the present invention. The lowermost part 19 of the refractory wall is inclined > 90° from horizontal but less than the inclination of the main part of the refractory wall. Figure 5 shows still another embodiment of the present invention, where the lowermost part 19 is inclined to form an angle < 90° from the horizontal.

Figure 6 shows one embodiment of the present invention where a ledge 22 is disposed in the refractory wall 16 at a point 200-1100 mm above the grid plate 7. The ledge 22 will change the direction of downflowing particles and prevent fine particles from clogging the holes 6 in the grid plate.

While the invention has been described in connection with what is presently considered to be the most practical and preferred embodiment, it is to be understood that the invention is not to be limited to the disclosed embodiment, but on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims.

Reference signs in the claims are intended for better understanding and shall not limit the scope.

Claims

1. A fast fluidized bed reactor (1) comprising:
an upright combustion chamber (2) having an upper region with generally vertical peripheral walls (14) and a lower region with at least one generally downwardly and inwardly inclined peripheral wall (16) having a flow of a relatively dense layer of particles downwardly close to its surface;
an inlet (3) in said combustion chamber for particulate material to be reacted;
an outlet (8) disposed in the upper region of said combustion chamber for exhausting gas;
a windbox (5) beneath said combustion chamber for providing fluidizing gas to said combustion chamber;
a grid plate (7) between said windbox (5) and said combustion chamber (2), said grid plate having openings (6) for supplying gas from said windbox to said combustion chamber at a sufficient velocity to fluidize particulate material in the combustion chamber and to transport a portion of the particulate material out of the combustion chamber with the discharged exhaust gas;
a particle separator (9) connected to said exhaust gas outlet (8) for separating entrained particles from the exhaust gas, said separator having an outlet (10) for clean gas and an outlet (11) for

particles connected to the lower part (17) of the combustion chamb r for recycling the separated particles into the combustion chamber;
means (18, 19, 21, 22) inwardly of said inclined wall (16) having a flow of a relatively dense layer of particles downwardly close to its surface and above said grid plate (7) for changing the direction of the particles (20) flowing downwards close to the inclined wall for preventing clogging and backflow of particles through the openings (6) into the windbox; and
said changing means (18, 19, 21, 22) being disposed adjacent the inclined wall (16) for directing the particles to flow in a direction away from the wall.

2. A fast fluidized bed reactor according to Claim 1 **characterized** in that said changing means (18, 19, 21, 22) is located at a height of 200-1100 mm above said grid plate (7) and adjacent the wall at a height less than 1100 mm from the grid plate.

3. A fluidized bed reactor according to Claim 1 **characterized** in that said combustion chamber (2) includes a second generally downwardly and inwardly inclined wall in the lower region thereof and disposed opposite the first mentioned wall.

4. A fluidized bed reactor according to Claim 1 **characterized** in that the wall (16) about the entire periphery of the lower region of the combustion chamber are generally downwardly and inwardly inclined.

5. A fluidized bed reactor according to Claim 1 **characterized** in that the lower region (17) has conical-shaped walls.

6. A fluidized bed reactor according to Claim 1 **characterized** in that walls (16) in the lower region are refractory walls.

7. A fluidized bed reactor according to Claim 1 **characterized** in that the inclined wall (16) forms an angle with the horizontal that ranges from 100 to less than 120°.

8. A fluidized bed reactor according to Claim 1 **characterized** in that the means (18, 19, 21, 22) for changing the direction of the particles flowing downwardly is disposed at a height below the inlet (3) for particulate material.

9. A fluidized bed reactor according to Claim 1 including an inlet opening (13) to said combustion chamber (2) for flowing the separated particles into the combustion chamber, said changing means (18, 19, 21, 22) being disposed at a height below said inlet opening for flowing the separated particles into the combustion chamber.

10. A fluidizing bed reactor according to Claim 1 **characterized** in that said changing means (18, 22) has a surface for directing particles into positions for entrainment by fluidizing gas.

11. A fluidizing bed reactor according to Claim 1 **characterized** in that said changing means (19) includes a wall surface forming an angle with said inclined wall (16) surface and an angle with the horizontal of < 100°.

12. A fluidizing bed reactor according to Claim 11 **characterized** in that the changing means (19) comprises a wall surface (16) forming an angle with said inclined wall surface and an angle with the horizontal substantially equal to 90°.

13. A fluidized bed reactor according to Claim 12 **characterized** in that said downwardly and inwardly inclined wall f(16) is vertical at its lowermost part at a location less than about 200-1100 mm above the grid plate.

14. A fluidized bed reactor according to Claim 1 **characterized** in that said changing means (19) includes a wall surface forming an angle with said inclined wall surface and forming an angle with the horizontal of less than 90°.

15. A fluidized bed reactor according to Claim 1 **characterized** in that a step (18) is provided in the lowermost of the slanting wall at an elevation about 200-1100 mm above said grid plate.

16. A fluidized bed reactor according to Claim 1 **characterized** in that a step (18) is provided at the lowermost part of the inclined wall at an elevation about 300-1000 mm above said grid plate.

17. A fluidized bed reactor according to Claim 1 **characterized** in that a step (18) is provided at the lowermost part of the inclined wall at an elevation about 300-700 mm above said grid plate.

18. A fluidized bed reactor according to Claim 15 **characterized** in that the step (18) has a depth of 50-300 mm.

19. A fluidized bed reactor according to Claim 15 **characterized** in that the step (18) has a depth of 100-150 mm.

20. A fluidized bed reactor according to Claim 1 including a ledge (22) disposed in the inclined wall (16) at a height about 200-1100 mm above the grid plate.

21. A fluidized bed reactor according to Claim 1 **characterized** in that said changing means (18, 19, 21, 22) is disposed at an elevation above the nozzles supplying fluidizing air.

22. A fluidized bed reactor according to Claim 1 **characterized** in that said changing means (18, 19, 21, 22) extends generally horizontally continuously across the whole width of the inclined wall.

23. A method of operating a fast fluidizing bed reactor for combusting particulate material comprising the steps of:
supplying fluidizing gas to a combustion chamber through distributors in a grid plate at a sufficient velocity to fluidize the particulate material and transport a substantial portion of the particulate material out from the combustion chamber with exhaust gases;

separating particles from the exhaust gas and recycling the separated particles to the combustion chamber;
changing the direction of particles, flowing downwardly along lower parts of peripheral walls in the combustion chamber at a height 200-1000 mm above the grid plate; and
causing the particles to flow in a direction so that the particles become influenced by the gas flowing through the distributors in the grid plate.

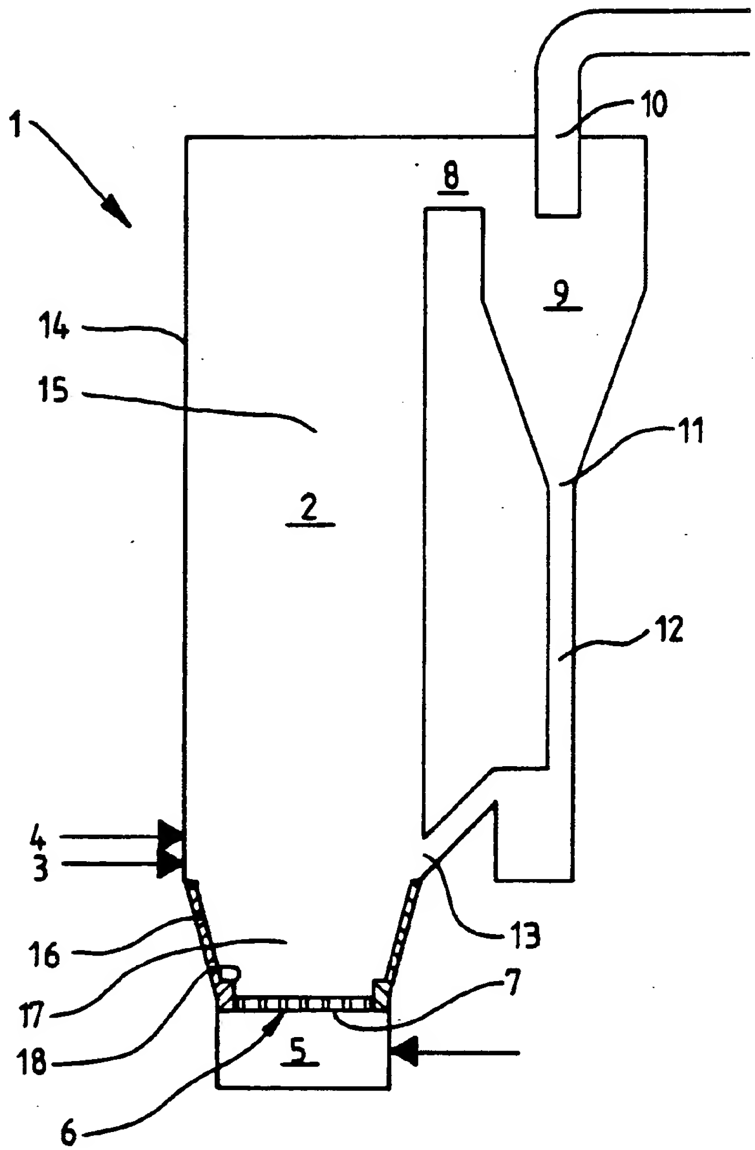

FIG.1

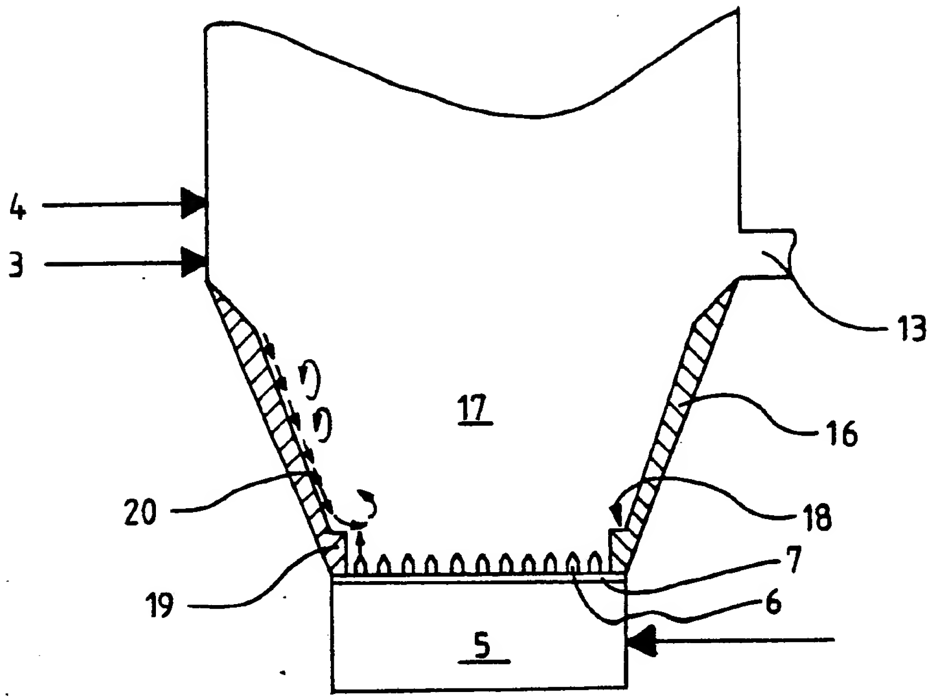

FIG. 2

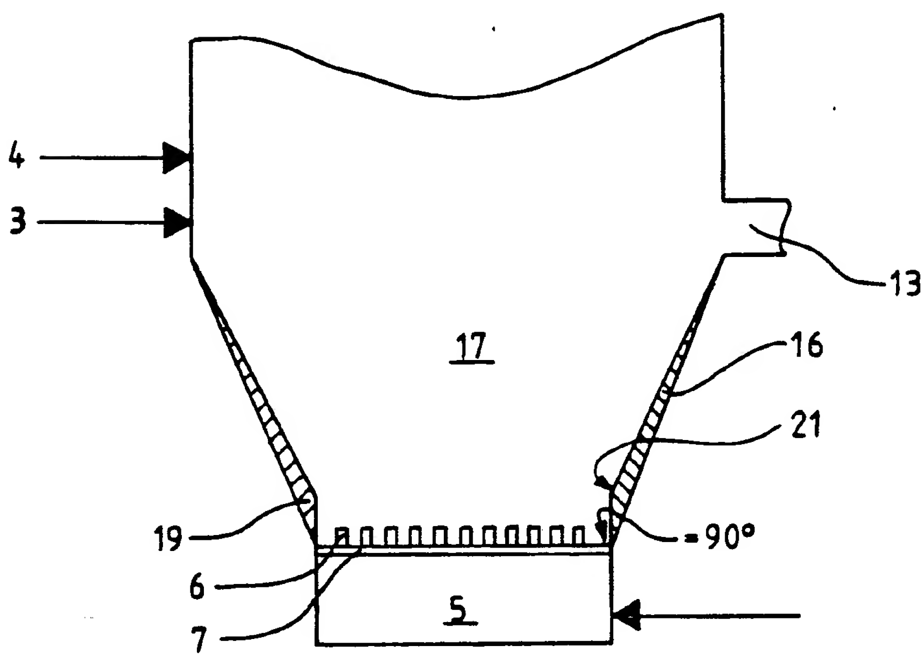

FIG. 3

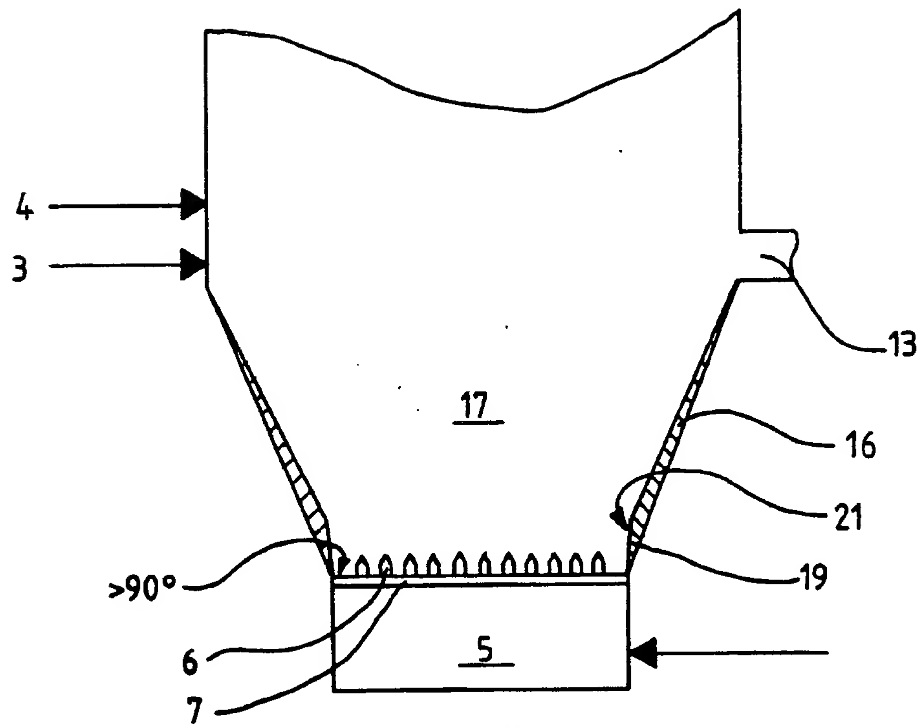

FIG. 4

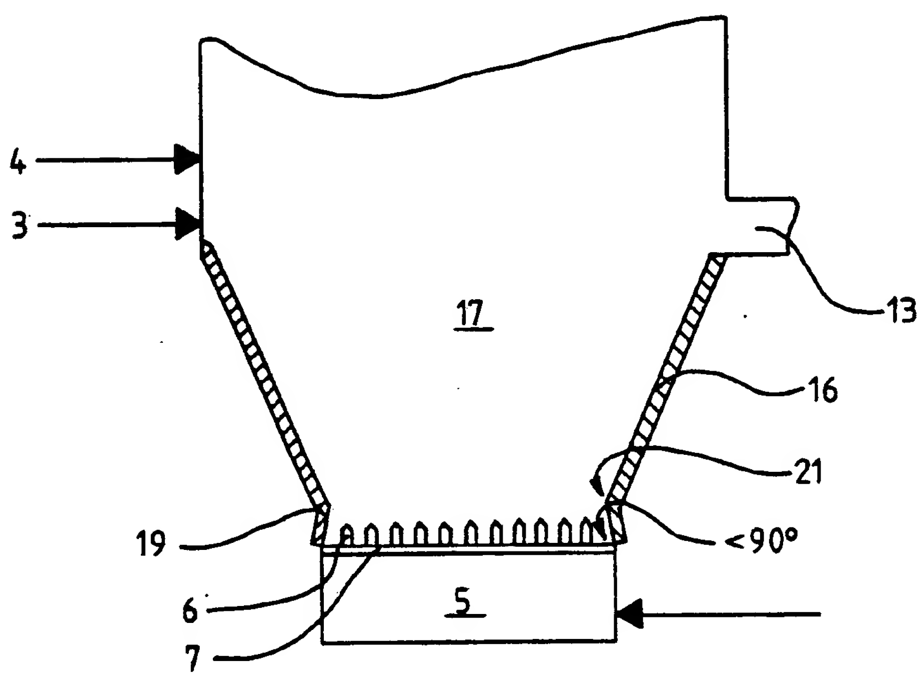

FIG.5

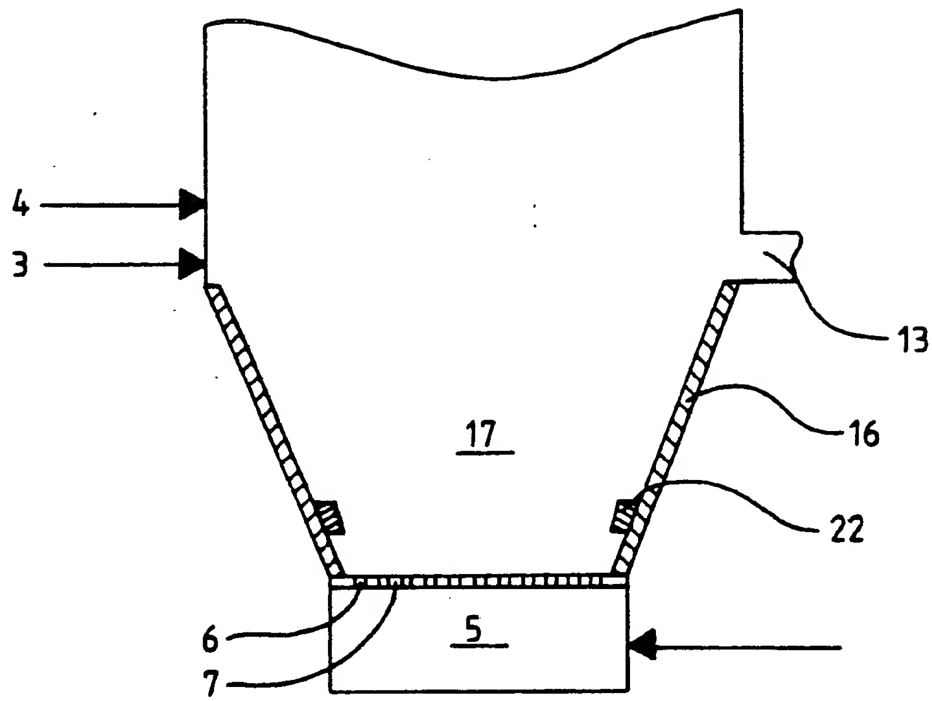

FIG. 6